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This grant was an AASERT award that was part of the AFOSR PRET Center on Robust Nonlinear Control Theory with Applications to Aerospace Vehicles, which operated from 1995-2000. This AASERT award augmented the parent grant and was focused on developing real-time algorithms for generation of feasible trajectories for mechanical systems that respect the input constraints (actuator magnitude and rate limits). The focus of the PRET center was fundamental research in general methods of analysis and design of complex uncertain nonlinear systems. We worked to create new mathematical theory as well as do the necessay work to make that theory help engineers solve a variety of real industrial problems. Caltechn's Control and Dynamical Systems department (CITCDS) was created with precisely this goal, and our industrial collaborators, led by Honeywell, gave us a proven team. The University of Minnesota contributed valuable application and experimental expertise, and an academic team member geographically co-located with Honeywell, facilitating personnel exchange.

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Robust Nonlinear Control Theory with Applications to Aerospace Vehicles

AASERT Grant

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Control and Dynamical Systems
California Institute of Technology
Pasadena, CA 91125

Final Report
1 June 1997 to 31 December 2000

1 Background and Objectives

This grant was an AASERT award that was part of the AFOSR PRET Center on Robust Nonlinear Control Theory with Applications to Aerospace Vehicles, which operated from 1995–2000. This AASERT award augmented the parent grant and was focused on developing real-time algorithms for generation of feasible trajectories for mechanical systems that respect the input constraints (actuator magnitude and rate limits).

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The main tasks that were to be addressed under this program were:

1. Numerical algorithms and the development of software for solving real-time trajectory generation algorithms in the presence of magnitude and rate constraints
2. Clearer understanding of the limitations and conservatism using these techniques.
3. Initial application of these techniques to the Caltech ducted fan, a nonlinear flight control experiment.

The ultimate goal of the research is to make these methods applicable to a wide class of realistic engineering systems, and easily accessible to control engineers.

2 Accomplishments

This is an AASERT award that funded Mark Milam, who is currently finishing his PhD in CDS at Caltech. The work performed under this grant concentrated on methods for real-time generation of trajectories that extend traditional optimal control techniques to allow real-time operation. The approach we studied begins with trajectories using a differentially flat approximation of the system, followed by a collocation technique to compute an optimal trajectory that satisfies the constraints. Substantial progress was made on this grant in getting the code to run at real-time speeds using a dedicated dSPACE real-time computing sysystem.

A key contribution of the work sponsored by this grant was the development of the first version of Caltech's Nonlinear Trajectory Generation (NTG) software, first reported in [2]. This software package implements the algorithsm developed under this grant and make use of B-splines and the NPSOL numerical optimization package to provide an extremely fast trajectory generation module. NTG is not an integral part of many activities within CDS, including use in the AFOSR PRET program (now ended), the AFOSR project on "Formation Flight of Microsatellite Clusters" (Murray and Marsden), and the DARPA Software Enabled Control (SEC) program.

A substantial amount of the effort on this grant was on the Caltech ducted fan itself. The experimental platform was been updated to better reflect the longitudinal dynamics of an aircraft. This involved reconstructing the thrust vectoring nozzle and using a larger wing surface. System identification experiments on the new system show long and short period instabilities that are consistent with a vehicle at this scale. The experimental modifications were reported in a paper presented at the Conference on Control Applications [1].

3 Personnel Supported

Mark Milam, Caltech graduate student (graduation expected by June 2002).

References

[1] M. B. Milam and R. M. Murray. A testbed for nonlinear flight control techniques: The Caltech ducted fan. In *Proc. IEEE International Conference on Control and Applications*, 1999.

[2] M. B. Milam, K. Mushambi, and R. M. Murray. A computational approach to real-time trajectory generation for constrained mechanical systems. In *Proc. IEEE Control and Decision Conference*, 2000.